

**TOWARD GREEN BUILDINGS:  
DESIGN, DEVELOPMENT AND PERFORMANCE  
EVALUATION OF A SOLAR-POWERED  
ABSORPTION COOLING SYSTEM**

Thesis by  
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### Certificate of Original Authorship

I hereby declare that this submission is my own work and has not previously been submitted for a degree and to the best of my knowledge it does not contain materials published and written by another person, nor the materials which have been accepted for the award of any other degree except where due acknowledgement is made in this thesis.

I, in addition, certify that this thesis has been written by me except to the extent that assistance from others is fully acknowledged. I also certify that all information sources and literature quoted are indicated in this thesis.

Vahid Vakiloroya

## ABSTRACT

**TOWARD GREEN BUILDINGS: DESIGN, DEVELOPMENT AND  
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Conventional HVAC systems rely heavily on energy generated from fossil fuels, which are being rapidly depleted. This together with a growing demand for cost-effective infrastructure and appliances has necessitated new installations and major retrofits in occupied buildings to achieve energy efficiency and environmental sustainability. As well as contributing to negative environmental outcomes, HVAC system usage is having a serious impact on electrical infrastructure. As such, the development of clean energy air conditioning units remains an urgent engineering challenge. Solar HVAC systems, which convert thermal energy into cool air, are known to be an efficient source of heating and cooling. Unlike traditional HVAC systems, solar air conditioning units produce maximum cooling capacity when the sun is fierce; that is, they are most efficient during the hottest part of the day, in stark contrast to traditional air conditioning units, which are less effective as temperatures increase.

This study represents a synergetic framework of system identification, design, development and performance evaluation of a newly-configured air conditioning system to target energy efficiency and environmental sustainability in buildings. In this study, we have originally designed and developed a single-effect lithium bromide (LiBr)-water absorption air-conditioning system in which hot water is fully supplied by vacuum solar collectors without using any other energy sources such as gas or electricity. Water-cooled condenser of the chiller is supported by a cross-flow cooling tower. In this system, by using water as the working fluid (refrigerant), one can avoid the use of ozone-depletion chlorofluorocarbons and hydro chlorofluorocarbons. Thermodynamic and heat transfer models for absorption chiller components are described in detail. Using these models, a computer simulation software named ABSYS is developed to design the absorption chiller and drive its optimum operating conditions.

Thermodynamic design data for single-effect absorption chiller are presented together with the possible combinations of the operating temperatures and the corresponding concentrations in the absorber and generator. The effect of various operating conditions on the performance and output of the absorption refrigeration system are then evaluated.

Another computer code is developed by using TRNSYS to evaluate the transient performance of the entire system. Several field tests are carried out to demonstrate the technical feasibility of the system. The utilisation of the solar energy as the heat input to the generator of the absorption chiller is reported. Since Australia has great solar resources and large air condition demand, this system can be uniquely suited in Australia. However, absorption cooling technology and especially the application of solar energy in this technology is still in its infancy in Australia.

The proposed design can be helpful to accelerate a global clean society to achieve its sustainable targets, especially in Australia, which has untapped high potential to become a World's green country. Work on this thesis, supported partially by The NSW Government through its Environmental Trust, is therefore aimed to design and explore sustainable solar-powered absorption air conditioning system to show the viability of this system in Australia and reduce the energy consumption of an air-conditioned building by using this eco-friendly cooling technology.

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## NOMENCLATURE

$A$	area (m <sup>2</sup> )
$A_{cross}$	cross sectional area (m <sup>2</sup> )
$A_m$	mean surface area (m <sup>2</sup> )
$A_o$	outside area (m <sup>2</sup> )
$A_v$	surface area of water droplets per tower cell exchange volume (m <sup>2</sup> )
$Cap$	capacity (kW)
$COP$	coefficient of performance
$C_p$	heat capacity (kJ/(kg°C))
$CR$	circulation ratio
$CV$	coefficient of variance
$C_{cover}$	cloudiness factor
$C_s$	average saturation slope of the air enthalpy versus temperature
$D$	diameter (m)
$D_e$	equivalent diameter (m)
$e_o$	emittance
$Fr_{Di}$	inside fouling factor
$Fr_{De}$	outside fouling factor
$f_i$	design energy input fraction
$f_o$	design energy input fraction
$g$	gravitational acceleration (m <sup>2</sup> /s)
$h$	enthalpy (kJ/kg)
$h_{s,w,e}$	Enthalpy of the saturated air entering the cooling coil (kJ/kg)
$I_t$	Total solar radiation intensity (W/m <sup>2</sup> )
$I$	Total horizontal radiation (W/m <sup>2</sup> )
$I_{bT}$	beam radiation incident (W/m <sup>2</sup> )

$I_d$	diffuse radiation incident (W/m <sup>2</sup> )
$k$	thermal conductivity (W/m °C)
$k_T$	ratio of total radiation on the horizontal surface to the extraterrestrial radiation
$L$	length (m)
$L_d$	thermal developing length (m)
$M$	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
$n$	number of tubes
$Nu$	Nusselt number
$Ntu$	overall number of transfer units
$P$	pressure (mm Hg)
$P_w$	wetted area (m <sup>2</sup> )
$P_{atm}$	atmospheric pressure
$P_h$	atmospheric pressure at the height of h
$Pr$	Prandtl number
$Q$	heat transfer capacity (kW)
$RE$	relative error
$Re$	Reynolds number
$R_r$	ratio of the reflected radiation on the tilted surface to the total radiation on the horizontal surface
$RMSE$	root mean square error
$RH$	relative humidity
$s_x$	standard deviation
$T$	temperature (°C)
$\Delta T_m$	logarithmic mean temperature difference (°C)
$t$	time (sec)
$t_p$	plate thickness (m)
$U$	overall heat transfer coefficient (kW/(m <sup>2</sup> °C))



$v$	Water velocity (m/s)
$V_{cell}$	total cooling tower cell exchange volume (m <sup>3</sup> )
$W_p$	input work of pump (kW)
$X$	LiBr-water concentration
$y_{data,i}$	measured variables
$y_{data,m}$	average value of data
$\mu$	absolute viscosity (kg/m.s)
$\nu$	kinematic viscosity (m <sup>2</sup> /s)
$\alpha$	heat transfer coefficient (kW/m <sup>2</sup> °C)
$\alpha_i$	heat transfer coefficient inside the tube (kW/(m <sup>2</sup> °C))
$\alpha_o$	heat transfer coefficient outside the tube (kW/(m <sup>2</sup> °C))
$\alpha_d$	average heat transfer coefficient in thermal developing region (kW/(m <sup>2</sup> °C))
$\alpha_c$	convective heat transfer coefficient due to evaporation of the liquid films (kW/(m <sup>2</sup> °C))
$\rho$	density (kg/m <sup>3</sup> )
$\rho_{gr}$	ground reflectance
$\beta$	solar collector slop
$\gamma$	surface azimuth
$\gamma_s$	solar azimuth angle
$\omega$	mean hour angle of time step
$\delta$	solar declination angle
$\lambda$	thermal diffusivity (m <sup>2</sup> /s)
$\eta$	second law efficiency
$\eta_{col}$	solar collector efficiency
$\varepsilon$	effectiveness
$\psi$	solar altitude angle
$\theta$	angle of incidence of beam radiation on the surface
$\theta_z$	solar zenith angle

$\varphi$	latitude
$\tau\alpha$	transmittance-absorptance product

## Subscripts

$a$	air, absorber
$act$	actual
$adp$	dew-point
$aux$	auxiliary
$amb$	ambient
$atm$	atmospheric
$b$	beam
$c$	condenser
$cap$	capacity
$cc$	cooling coil
$col$	collector
$chw$	chilled water
$cw$	cooled water
$ct$	cooling tower
$Cu$	copper
$d$	diffuse
$db$	dry-bulb
$e$	evaporator, entering
$equ$	equivalent
$elec$	electricity
$f$	fluid
$g$	generator
$gl$	glass
$gr$	ground
$h$	height
$hw$	hot water
$hx$	heat exchanger
$k$	Kelvin

<i>i</i>	inside
<i>l</i>	liquid
<i>m</i>	mean
<i>max</i>	maximum
<i>n</i>	normal
<i>nom</i>	nominal
<i>o</i>	outlet, outside
<i>pl</i>	plate
<i>pred</i>	predicted
<i>ref</i>	refrigerant
<i>sat</i>	saturated
<i>s</i>	solution
<i>sh</i>	superheated
<i>ss</i>	strong solution
<i>sup</i>	supply
<i>t</i>	tank
<i>tr</i>	transition
<i>v</i>	vapour
<i>w</i>	Water, wet
<i>ws</i>	weak solution
<i>x</i>	point on the cooling coil where condensation beings

## ABBREVIATION

ABSYS	Absorption System Simulation
AIRAH	Australian Institute of Refrigeration, Air Conditioning and Refrigeration
ARA	Australian Refrigeration Association
ASHP	Air Source Heat Pump
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
AUD	Australian Dollar
CLF	Cooling Load Factors
CLTD	Cooling Load Temperature Differences
CO <sub>2</sub>	Carbon Dioxide
CO <sub>2</sub> -e	Carbon Dioxide Equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organization
CV	Coefficient of Variance
DEC	Direct Evaporative Cooling
DP	Dew-Point
DX	Direct Expansion
ECC	Evaporative-Cooled Condenser
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
GWh	Gigawatt hour
GWP	Global Warming Potential
HVAC	Heating, ventilation and air conditioning
kWh	Kilowatt hour
LMTD	Logarithmic Mean Temperature Difference
ODP	Ozone Depletion Potential
Mt	Megatonne, or million tonnes
PJ	Petajoule
PCM	Phase Change Material
PV	Photovoltaic

PLC	Programmable Logic Controller
RE	Relative Error
RMSE	Root Mean Square Error
RT	Refrigeration Tons
SCL	Solar Cooling Load
TFM	Transfer Function Method
TRNSYS	Transient System Simulation
VB	Visual Basic